New fits of the unintegrated gluon density

A. Bacchetta (Università di Pavia), H. Jung (DESY),
A. Knutsson (DESY), K. Kutak (Antwerp),
F. S-Himmelstjerna (DESY)

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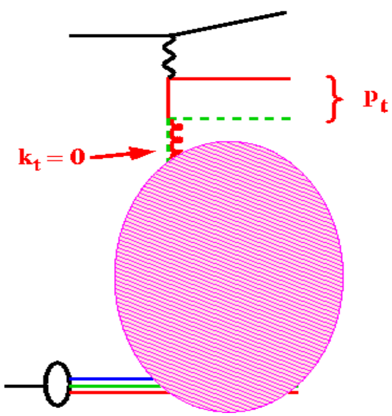
Outline

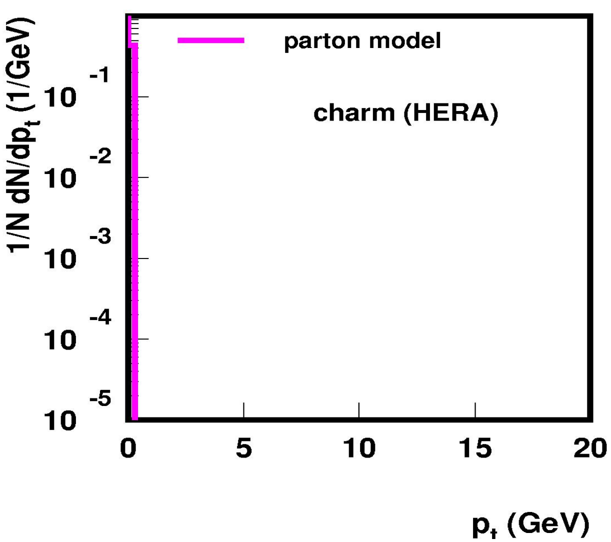
- Introduction to unintegrated PDFs
- The fitting method
- Results

Introduction

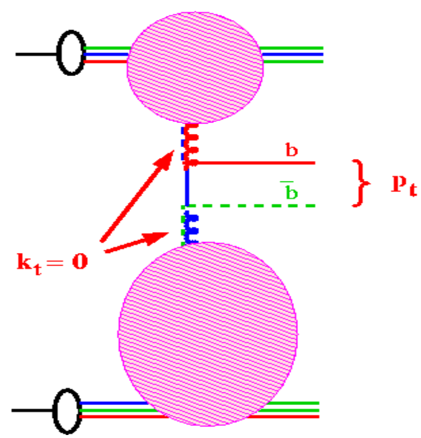
J. Collins, H. Jung hep-ph/0508280

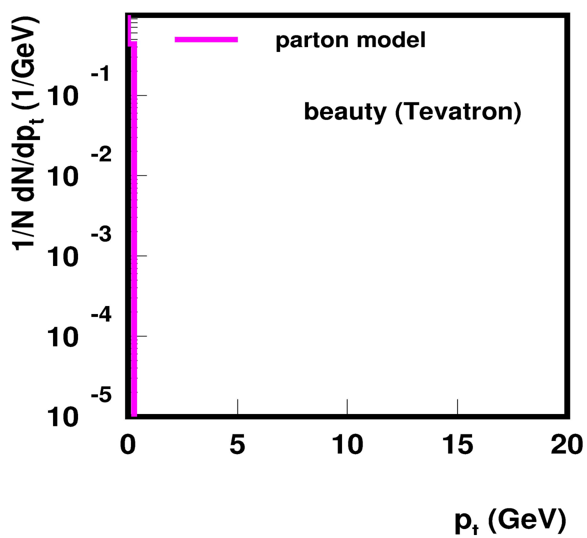
Heavy quark production at HERA



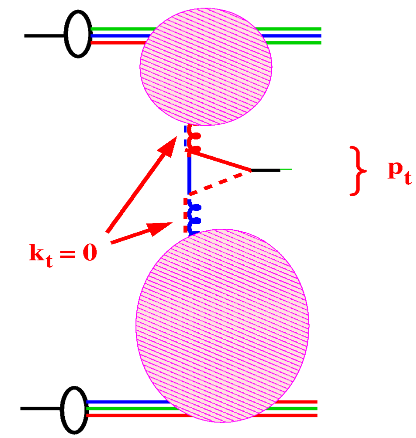


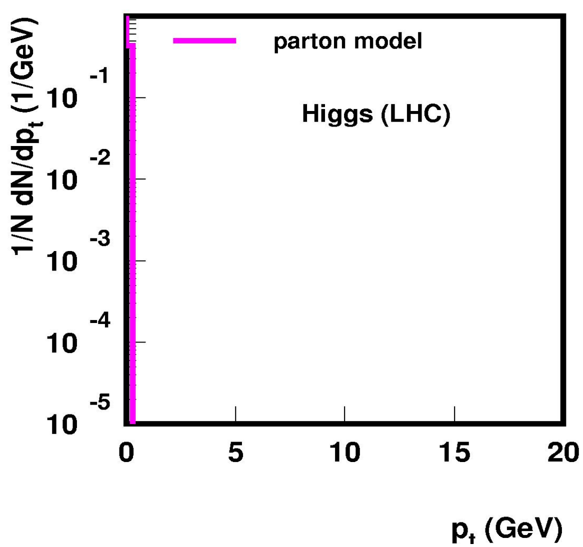
Heavy quark production in pp collisions





Higgs production in pp collisions





Introduction

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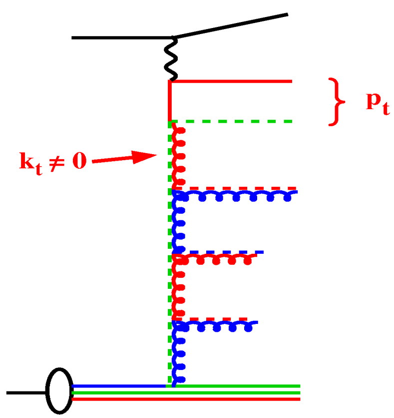
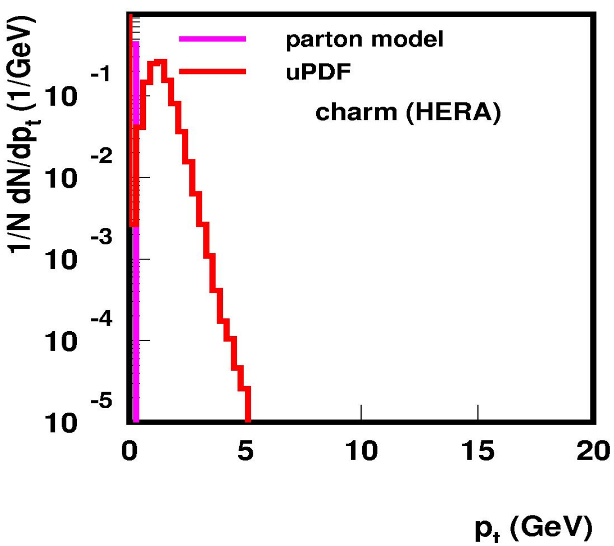
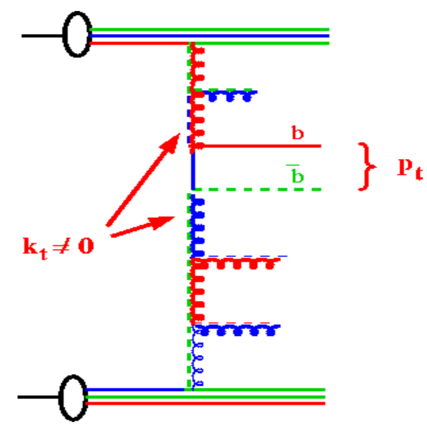
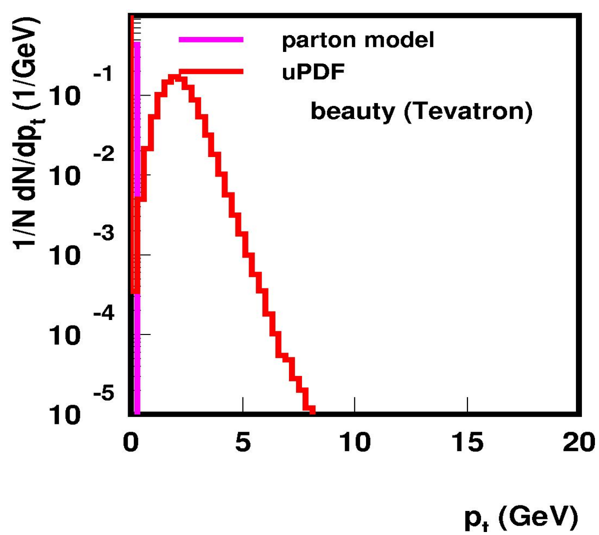
Heavy quark production at HERA



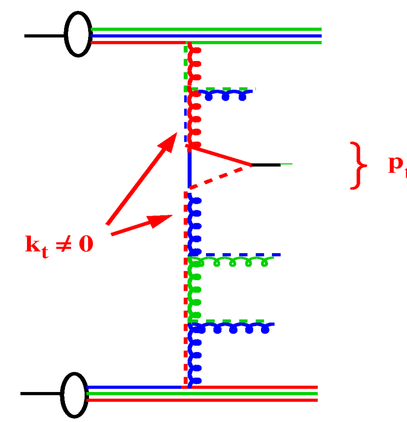


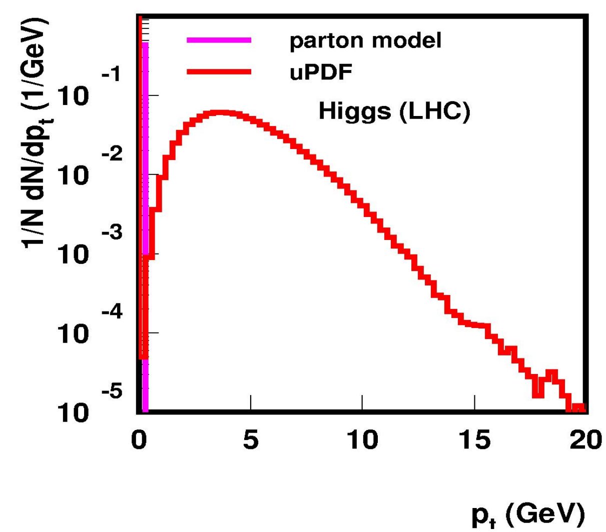
Heavy quark production in pp collisions





Higgs production in pp collisions





→ **Kinematics correctly treated by using unintegrated PDFs. Gives significant transverse momentum to the final state.**

Different approaches

• Take derivative from PDF:

$$f(x, k_\perp^2) \sim \frac{d\Delta x g(x, k_\perp^2)_{\mathrm{DGLAP}}}{d \log k_\perp^2}$$

• The KMR approach. Use normal PDFs. Let the last emission generate transverse momentum via the Sudakov form factor.

→ **Can be used in the DGLAP approach, where a strong ordering in k_t is assumed.**

In this talk:

•**CCFM (Catani Ciafaloni Fiorani Marchesini) approach.**

Parton evolution with angular ordering instead of strong ordering in k_t.

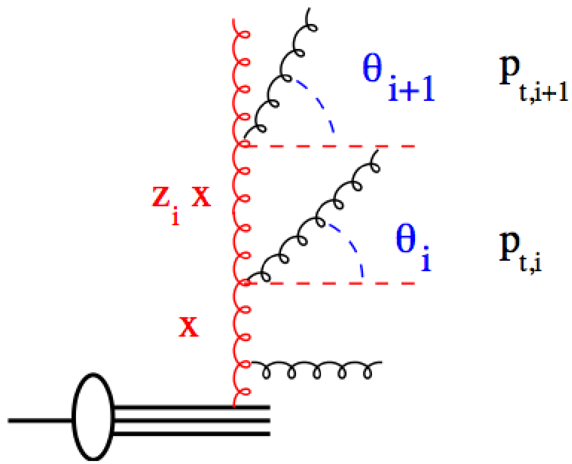
Use a unintegrated PDF – take k_t dependence into consideration from start

CCFM and CASCADE MC generator

- **uPDF starting disitribution (example):**

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot (1-Dx) \cdot \exp\left(-\frac{(k_T-\mu)^2}{2\sigma^2}\right)$$

- **Defined at some starting scale and evolved to higher scales by emissions of gluons according to the *CCFM* evolution scheme.**
Angular ordering of emitted gluon (Color coherence). No explicit k_t-ordering.



- **CCFM is usually referred to as the bridge between DGLAP and BFKL.**

- **CCFM and uPDFs are implemented in the ep/pp MC generator CASCADE (H. Jung, *Comput.Phys.Commun.143:100-111,2002*).**

The fitting approach

The fitting method

Former fitting method: Based on running the generator in an **iterative procedure** in parameter space.

→ **Time consuming for exclusive final states. A high statistics MC run can take more than 24h, and ~100 iterations needed to find minimum.**

New Approach: Describe **parameter dependence** **before parameter fitting**, by building up a ***MC grid in parameter space***.
The grid points can be calculated simultaneously.
(In best case it takes the time of running the MC once.)

Parametrize the parameter space with a polynomial.

A fit takes only a few seconds.

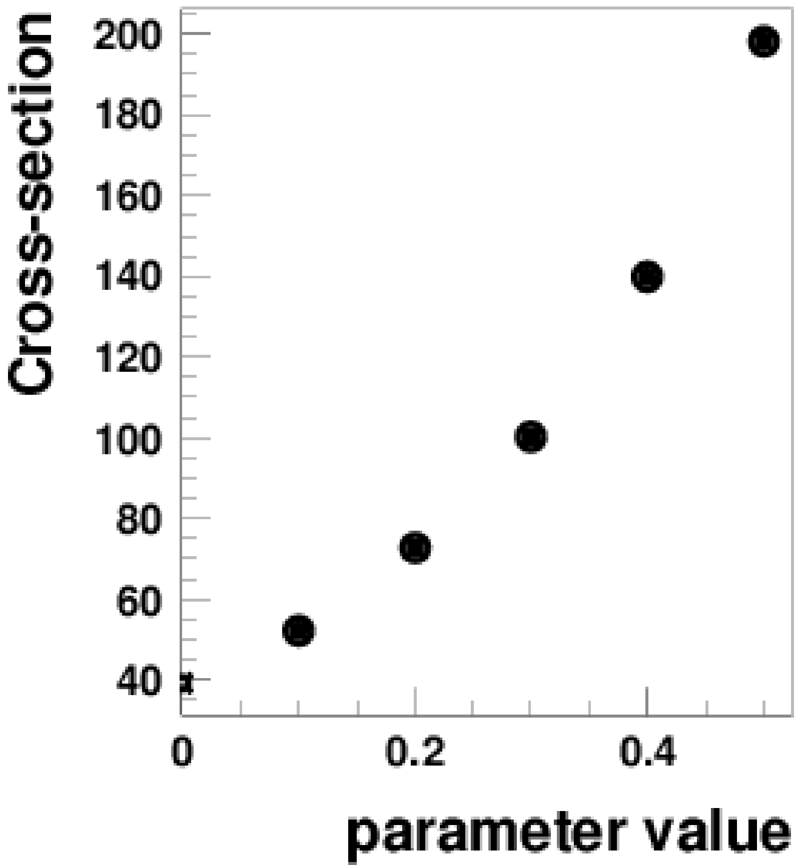
→ Very fast to remake fit for different kinematic ranges, starting values, fitting algorithms, error treatments, etc.

Simple Example

Simplest possible example

1 parameter, 1 data cross-section

1. Build up the grid



Monte Carlo predictions

Equidistant or random grid points.

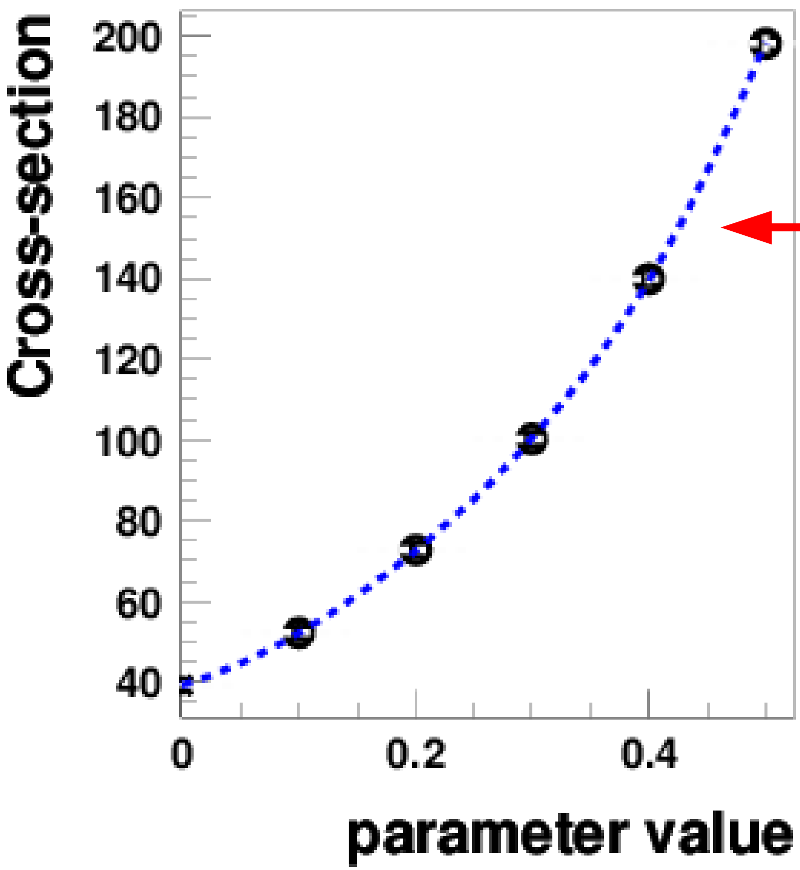
Multidimensional uPDF fit:
Random grid points.

Simple Example

Simplest possible example

1 parameter, 1 data cross-section

2. Determine polynomial using SVD



Monte Carlo predictions

Polynomial fit using singular value decomposition

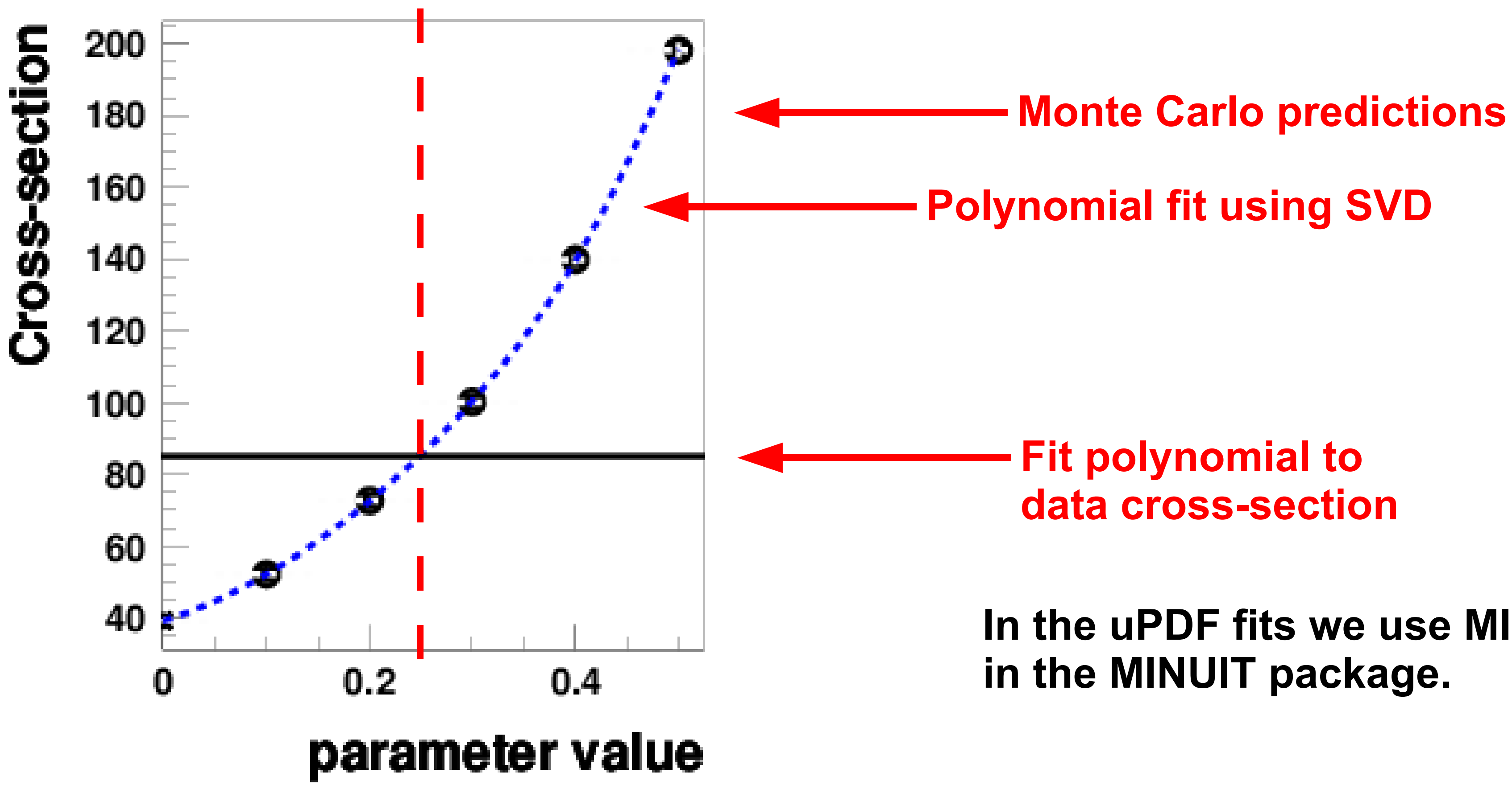
For the uPDF fits we use a 3rd or 4th order polynomial.

Simple Example

Simplest possible example

1 parameter, 1 data cross-section

3. Minimize Chi2 to data



In the uPDF fits we use MIGRAD in the MINUIT package.

Error treatment

- **The integration uncertainties are propagated to the polynomial. A co-variance matrix for the coefficients are calculated.**

- **The CTEQ χ^2 calculation** (*Phys.Rev.D65:014012,200, Stump et al*) **is used to take the correlated data uncertainties in the data into consideration.**

In the fit of the PDF parameters to the data the uncorrelated and the different correlated uncertainties can be treated separately according to:

$$\chi^2 = \sum \frac{(X_{\mathrm{Data}} - X_{\mathrm{Polynomial}})^2}{\alpha^2} - \Sigma_j \Sigma_{j'} B_j (A^{-1})_{jj'} B_{j'}$$

$\alpha^2 =$ **Sum of uncorrelated errors (data and polynomial)**

$\Sigma_j \Sigma_{j'} B_j (A^{-1})_{jj'} B_{j'} =$ **Term defined by the correlated systematic errors**

(See Phys.Rev.D65:014012,200, Stump et al for details.)

PROFFIT

- **The whole machinery is implemented in the program PROFFIT.**
  (Bacchetta, Jung, Knutsson, Kutak, DESY 10-013, arXiv:1001:4675)

- **Official release soon available on HEPFORGE.**
  (However contact me if you are interested.)

<u>Other applications:</u>

- **Also used to tune PYTHIA hadronization parameters to HERA data.**
  (see http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=74601)

- **Similar approach use by the program PROFFESSOR. Used for LHC and LEP tunes of UE and hadronization MC parameters.**

The fits of the uPDF

Determination of the parameters in the gluon density

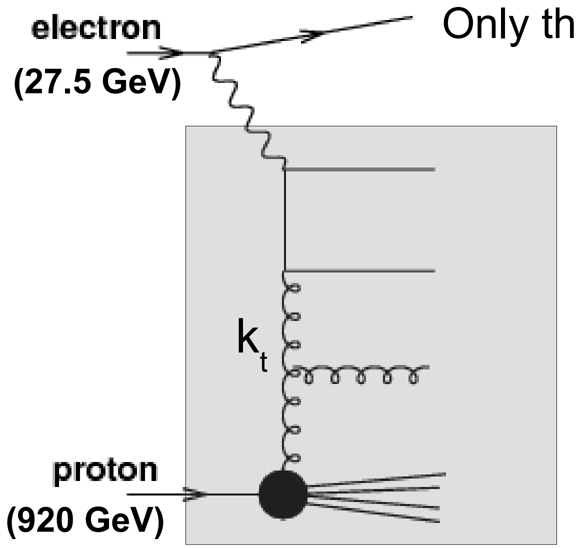
$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot (1-Dx) \cdot \exp\left(-\frac{(k_T-\mu)^2}{2\sigma^2}\right)$$

Used in the CASCADE MC generator:
Evolve PDF according to the CCFM equation.

•First goal determine the x-dependence.

•Use the proton structure function (sigma reduced for positrons).
Latest combined measurement from H1 and ZEUS. (JHEP 1001:109 (2010))

Should be fairly insensitive to the kt-dependent part of the gluon. Inclusive measurement with minimum restrictions on the hadronic final state.



Only the electron detected

“Dont care” about the rest

Fitting the x dependence to the proton structure - F2

The previous fits...

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot \exp\left(- \frac{(k_T - \mu)^2}{2\sigma^2} \right)$$

Previous fits to F2

The previous fits...

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot \exp\left(-\frac{(k_T - \mu)^2}{2\sigma^2}\right)$$

...was good enough for the "low" precision F2-data:

Fitting F2 in the range x < 0.005, 5 < Q^2 < 100 GeV^2, to the "old" structure function measured by H1 (Eur.Phys.J.C21:33-61,2001)

<u>Minimum</u>
N = 0.81 ± 0.02
B = 0.029 ± 0.004
C = 4 (fixed)
σ = 1 (fixed)
μ = 0 (fixed)
χ^2/ndf=1.2

Bacchetta, Jung, Knutsson, Kutak, Himmelstjerna, arXiv:1001-4675 DESY 10-013

This is a **good fit** which **reconstructs** the parameter values in a **former official PDF** *(Jung, Kotikov, Lipatov, Zotov, hep-ph/0611093)* fitted to the same data with the previous fitting approach.
Good validation of the new fitting approach.

New fits

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot \exp\left(-\frac{(k_T - \mu)^2}{2\sigma^2} \right)$$

- Fit to latest ***high precision*** **combined F2 data from H1 and ZEUS (JHEP 1001:109 (2010))**

- **$x < 0.005$, $5.0 < Q^2 < 100.0$ GeV^2**

Minimum (old fit)
N = 0.81 ± 0.02
B = 0.029 ± 0.004
C = 4 (fixed)
σ = 1 (fixed)
μ = 0 (fixed)
χ^2/ndf=1.2

Bacchetta, Jung, Knutsson, Kutak, Himmelstjerna, arXiv:1001-4675 DESY 10-013

Minimum (fit to new data)
N = 0.83 ± 0.02
B = 0.017 ± 0.003
C = 4 (fixed)
σ = 1 (fixed)
μ = 0 (fixed)
χ^2/ndf=5.1

Roughly the **same minimum**, but a significantly higher χ^2.

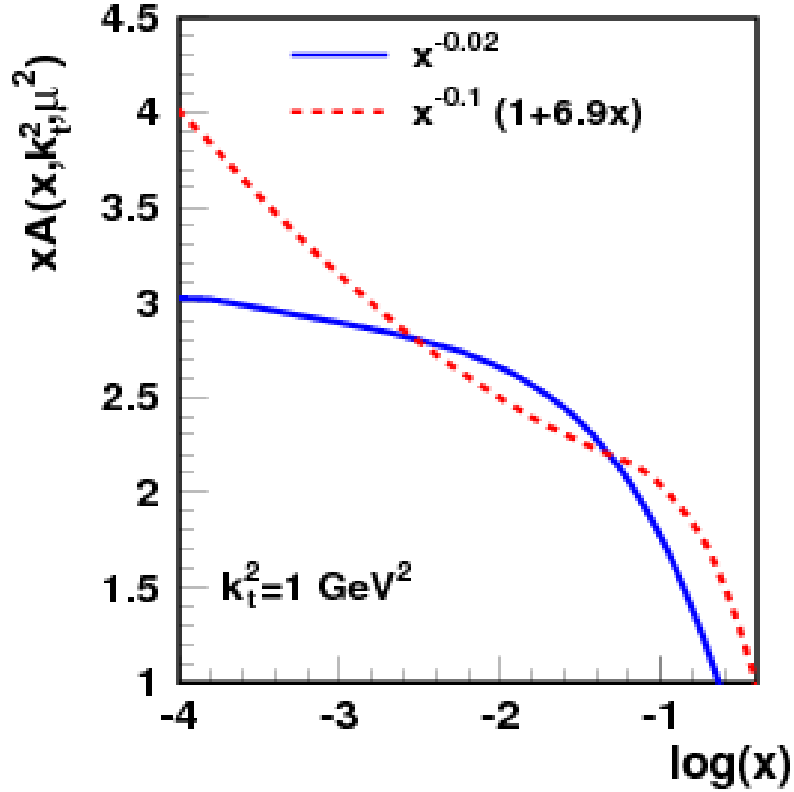
High precision data requires more from the model.

New parameterization

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1 - Dx) \cdot (1 - x)^C \cdot \exp\left(- \frac{(k_T - \mu)^2}{2\sigma^2} \right)$$

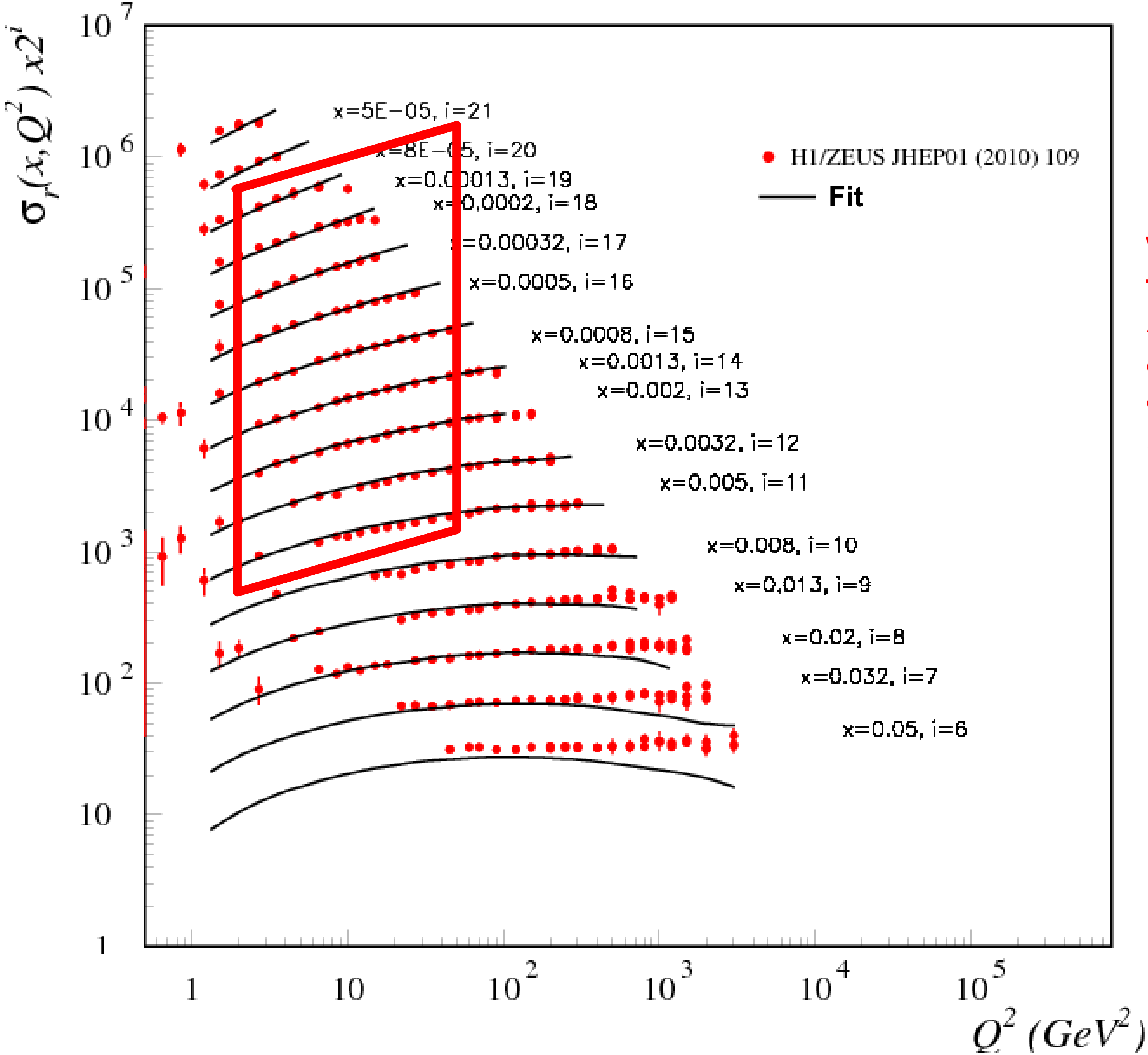
- *(1-Dx)* gives additional freedom to the gluon
- **$0.0001 < x < 0.005$, $2.0 \leq Q^2 < 50$ GeV^2**
- Significant improvement of the fit

<u>Minimum</u>
N = 0.47 ± 0.03
B = 0.11 ± 0.01
D = -6.9 ± 0.9
C = 4 (fixed)
σ = 1 (fixed)
μ = 0 (fixed)
χ^2/ndf=186.8/85=2.2



The new gluon is more pronounced at low and high x.

Results



= *included in fit*

χ^2/ndf=2.2

With only *3 parameters* fitted, the *gluon* in the *k_t-factorization* scheme gives a decent description of the data *within the fitted range.*

...but room for improvements.

Parameterization of PDF. (More freedom in fit...)

Need contribution from quarks?

Sensitivity to other parameters:
E.g light quark mass.

Summary

- **Fitting approach based on describing the parameter dependence before the fits are executed.**
  --> *Very fast fits.*

- **Method with full error treatment implemented in PROFFIT.** (arXiv:1001-4675)

- **New fits of the unintegrated gluon densities have been performed to the high precision HERA data.**

- **With only 3 parameters fitted the non-collinear gluon gives a reasonable description of the fitted data.**

- **A lot of room for improvement of fit.**
  More freedom in fit: PDF parameterization.
  Inclusion of quarks needed?
  Sensitivity to other parameters, ...

albert.knutsson@desy.de

Back-up slides

All fits in this talk:
Λ_{QCD}= 0.2 GeV
$\mu_{renormalization} = 4m^2 + p_t^2$
$m_{light\ quarks}$ = 0.25 GeV

Di-jet data insensitivity to the x behavior

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot exp(-\frac{(k_T-\mu)^2}{2\sigma^2})$$

The small *x* behaviour (**B)** is roughly arbitrary as long as one choose (fit) the correct normalization, N.